Intermediation in Innovation[1]

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Abstract

The paper offers a new theoretical framework to examine the role of intermediaries between creators and users of new inventions. We find that uncertainty about the profitability of investing in new inventions generates a basis for intermediation. An intermediary may provide an opportunity to economize on a critical component of efficient investment decisions - the expertise to sort 'profitable' from 'unprofitable' inventions. Our findings may help explain the surge in university patenting and licensing since the Bayh-Dole Act of 1980. The study also identifies several limitations to the potential efficiency of intermediation in innovation.

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1 Introduction

One major constraint to the success of many invention-based ventures proves to be the high degree of uncertainty about their profitability (Arrow, 1962; Kamien and Schwartz, 1982). Apart from technical difficulties, it is often hard to assess the commercial value of inventions that may lead to entirely new products without knowing the demand for it. As a consequence, potential investors must act on expected values, and profitable new technology may not be adopted due to pessimistic beliefs. In this paper, we examine the role that intermediaries between creators, financiers, and users of new inventions can play in mitigating this uncertainty problem.

Obviously, such intermediaries exist. For instance, at most U.S. universities new faculty inventions are disclosed to a technology transfer office (TTO). The TTO evaluates the commercial value of these inventions and seeks potential investors who have the capability, interest and resources to take on the development of new technology. Normally, the TTO contacts several prospective licensees and eventually pursues one of them to negotiate a licensing contract.[1] Similarly, venture capitalists allocate financial resources from private investors to innovative entrepreneurs, typically in industries with large information gaps between investors and entrepreneurs.[2] Other examples include underwriters who locate potential investors with high valuations for the securities of new start-up firms, or technology-based business incubators who seek to link innovative entrepreneurs with potential industrial customers.

Despite their obvious presence, such innovation intermediaries have received little attention in the theoretical intermediation literature (see Spulber (1999) for a comprehensive survey). In this paper, we offer a new framework to analyze the reasons why such intermediaries may emerge and what role they play in the organization of innovation investments.

We consider what is perhaps the simplest model that still captures the essence of intermediation in innovation. Firms seek to invest in new technology, but are unable to estimate the value of new technology with certainty. As a consequence, investments fail to take place, even when the investor would realize positive gains from innovation. We show that this uncertainty about the profitability of innovation investments generates a basis for intermediation: an intermediary may provide the opportunity to economize on

[1] For more details, see the web pages of the Office of Technology Licensing at Stanford, <http://otl.stanford.edu/about/resources/history.html> and of the Association of University Technology Managers Web Page, <http://www.autm.net>.

[2] See Gompers and Lerner (1999) for a survey over the empirical venture capital literature.

the costs of expertise to identify new inventions and separate profitable from unprofitable ones. Of course, the acquisition of expertise by an intermediary generates asymmetric information between the intermediary and potential investors. We find, however, that even though the intermediary has no means to credibly reveal to firms the commercial value of a specific invention, the usage of success-based payments, such as royalties or equity, can sustain an equilibrium with intermediation if the intermediary has access to a sufficiently large number of inventions. The point is that success-based payments convince firms that the intermediary has an interest to choose the right match between firms and inventions. If the number of commercializable inventions is large, firms expect to obtain a profitable invention with high probability. This implies a high willingness to pay for intermediation. We show that there exists a threshold level for the number of inventions such that expected payments are, in aggregate, large enough to cover the costs of expertise investment whenever the number of inventions exceeds this threshold. Intermediation in innovation becomes then viable, considering all costs. The findings in our model are consistent with empirical evidence (e.g., Hsu and Bernstein, 1997; Siegel et al., 2000; Lamoreaux and Sokoloff, 2002).

We extend our basic model to multiple intermediaries. We show that the competition may be affected by the size of each intermediary's invention pool as well as the possibility to specialize on different licensee-firms.

The study also identifies several limitations to the potential efficiency of innovation investments. First, the intermediary may have an incentive to offer inventions of low profitability whenever there are less profitable inventions than potential investors. Second, the multiplicity of equilibria may introduce a high potential for coordination failure. Third, inefficiencies may arise from the competition between multiple intermediaries. We find that combining intermediation services, e.g. in regional networks, may be a way to enhance efficiency.

In the innovation literature, the paper most closely related appears to be that of Jensen and Thursby (2001). Besides presenting survey results for 62 U.S. universities, they consider a theoretical model of technology transfer. Their model assumes the presence of a TTO who is responsible for executing licensing contracts with potential investors. It is shown that the usage of royalty or equity contracts can mitigate a moral hazard problem with regard to inventor effort. In contrast, our paper explores the reasons why intermediaries, such as TTOs, emerge in the first place. We combine our basic intermediation model with that of Jensen and Thursby in Section 5. Related is also the work on venture capitalists by Chan (1983). However, the focus of Chan's paper is similar to that of Jensen and Thursby, and hence different from ours. We focus on the problem of uncertainty about the characteristics of a new invention and the corresponding question of whether an intermediary can reduce this uncertainty, whereas Chan does not address the uncertainty problem. Instead, his paper focuses on the moral hazard problem with inventor effort and the corresponding question of how inventors can be induced to expend more effort.[3]

Intermediation in markets where sellers and buyers are asymmetrically informed about the quality of a product is analyzed by Biglaiser (1993) and Lizzeri (1999). Biglaiser shows that the concern for reputation may induce an infinitely lived middleman, who buys and resells goods, to inspect the quality and signal it through his choice of price.[4] Lizzeri investigates the extent to which quality can be signalled by means of a certification agency, taking into account that the agency may benefit from information manipulation. Lizzeri considers the case of monopoly as well as oligopoly. In both papers, intermediaries serve as a device for signalling high quality, but play no active role otherwise. Macho-Stadler et al. (2004) study an intermediary's incentive for reputation building in the context of university-industry technology transfer. In their model, there is an infinitely-lived TTO who is perfectly informed about the quality of new inventions, while potential licensees are only imperfectly informed. The authors show that the repeated licensing game has an equilibrium in which the intermediary offers only profitable inventions if the frequency with which the intermediary obtains new inventions is high enough. In contrast to these papers, we assume that no party has private information initially. Furthermore, our analysis abstracts from any aspects of reputation building. Instead, we focus an intermediary's incentive to invest in information acquisition and use this information to match creators, financiers, and users of new inventions.

Caillaud and Jullien (2001) study a model of competing intermediaries who are able to match suitable trading partners. Competition in registration and transaction fees is shown to give rise to dominant firm equilibria that are similar to the equilibria with concentrated intermediation in our model. However, in contrast to our paper, an intermediary is endowed with expertise by assumption which makes truthful matching always credible in their model. Competition between intermediaries is also analyzed in Spulber (2002). His analysis focuses on investment incentives of potential trading partners.

[3] For a recent study of the role of intermediaries in mitigating moral hazard and opportunism, see Dixit (2001).

[4] The analysis is extended in Biglaiser and Friedman (1999) by allowing for free-entry competition between intermediaries.

In the next section we describe our basic intermediation model. Section 3 presents the equilibrium analysis. In Section 4 we consider multiple intermediaries. Section 5 endogenizes the role of inventors in our basic model. Section 6 concludes with a discussion of empirical evidence, policy implications, and directions for future research.

2 Model

In this section, we present our basic intermediation model. For concreteness in what follows, we shall use the example of university-industry technology transfer. Intermediation by venture capitalists, underwriters, and technology-based incubators could be modeled along similar lines. An analysis of these kinds of innovation intermediaries is discussed in Section 6.

Consider a situation with a set of inventors $N \equiv \{1, ..., n\}$, each of which having one invention, and a set of firms, $K \equiv \{1, ..., k\}$, each of which seeking to commercialize one invention.[5] We assume that $k \leq n$ (i.e. there are at least as many inventions as there are firms).[6] Inventors and firms are risk-neutral.

One of the key features of new inventions is that their return to adoption is uncertain. To capture this feature, let q denote the quality of an invention and assume that the adoption return is $q = V_H$ with probability p, and $q = V_L$ with probability $(1 - p)$, where $0 < p < 1$ and $0 < V_L < V_H$. If firm j adopts an invention of quality q_i, it obtains a return $\beta_j q_i$, where β_j represents firm j's efficiency level, with $\beta_1 \geq \cdots \geq \beta_k > 0$.[7] Firms are unable to observe the quality level of an invention before they make the investment. Let $A > 0$ be the lump-sum cost of commercializing an invention.

[5] That is, we assume implicitly that each firm has financial funds for only one innovation. An alternative interpretation is that, even if a firm has financial funds for more than one innovation, k represents the total number of innovation opportunities in the economy.

[6] The survey for 62 U.S. universities by Jensen and Thursby (2001) shows that it is in fact typically difficult to find even one potential licensee for a new technology resulting from university research.

[7] The assumption that there are only two types of inventions is made to simplify the analysis. One can verify that the results of the paper continue to hold in the case of more than two types. Notice that we capture a firm's efficiency level through the value that the firm can create by adopting any invention. Efficiency, on the other hand, can also be captured through lower cost of commercializing an invention. In other words, we could have multiplied the adoption cost A with a firm-specific efficiency parameter. Our results would continue to hold in such a case. In the alternative interpretation where firms can adopt more than one invention and k is number of innovation opportunities in the economy, the parameter β_j characterizes the efficiency level associated with the j's innovation opportunity.

We make the following two assumptions:

$$\beta_1 \left[pV_H + (1-p) V_L\right] < A \tag{A1}$$

$$\beta_k V_H > A \tag{A2}$$

Assumption A1 implies that even the most efficient firm would not adopt an invention of unknown quality. Assumption A2 implies that even the least efficient firm would adopt a high-quality invention when there is no uncertainty. Thus, a potential market for invention fails to exist due to uncertainty about the profitability of adoption.

We now introduce another agent, called the technology transfer office (TTO). The TTO is risk neutral. By making a sunk investment of $C > 0$, the TTO can acquire the expertise to recognize whether inventions are of high or low quality and assess the efficiency level of potential licensees.[8] Thus, C can, for instance, be interpreted as the cost of human capital development or the cost of hiring personnel with professional competence in specialized fields. For simplicity, we neglect any variable costs of evaluating inventions, which seems fairly in accordance with empirical observations.[9]

We assume that the TTO is part of a university that owns all new inventions. The model thus captures the situation of virtually all research universities in the United States (cf. Jensen and Thursby, 2001). Contractual agreements between inventors and the TTO are analyzed in Section 5. In Section 6, we address the question of optimal allocation of property rights.

The timing and nature of decisions by the TTO and firms are as follows. In stage 0, the TTO chooses a selection rule, denoted by σ, which is a complete plan on how to allocate (profitable and unprofitable) inventions to potential investors. Formally, let $\sigma = \{s_j\}_{j \in K}$ be a set of functions, where $s_j : \{1, ..., n\} \to \{0, 1\}$ for each $j \in K$. Here $s_j(m) = 1$ means that firm $j \in K$ receives a high-quality invention, and $s_j(m) = 0$ means that firm $j \in K$ receives a low-quality invention, when there are m high-quality inventions. We assume that $\sum_{j=1}^{k} s_j(m) \leq m$ and $k - \sum_{j=1}^{k} s_j(m) \leq n - m$. In stage 1, the TTO decides whether

[8] It can be shown that the results of our paper continue to hold if the intermediary would obtain only a noisy (but informative) signal about the commercial value of new inventions, or if firms have some a priori information about the profitability of adopting an invention. The critical point is that, even if firms possess some information, the intermediary can choose to get *better* informed by investing in expertise.

[9] See, e.g., Cohen and Levinthal (1989, 1990) and Lamoreaux and Sokoloff (2002) who observe that the cost of acquiring the ability to assess the value of new inventions is typically substantial compared to the immediate costs of information processing, which are often negligible. Moreover, the results obtained below continue to hold when there is a small cost of expertise per invention.

to invest in expertise or not. The investment is observable. If it does not invest, the game ends and payoffs to all players are zero. If it invests, it observes the number of high-quality inventions that are available, denoted by m, where $m \leq n$. In stage 2, the TTO offers an invention to each potential investors $j \in K$ according to σ, and simultaneously charges a royalty rate, ρ_j, for licensing the invention, where $\rho_j \in (0, 1]$ is a fraction of the firm's revenue from adopting the invention.[10] In stage 3, firms simultaneously decide whether to accept or reject the TTO's licensing offer.

We denote the set of firms that participate in technology transfer by P, and the cardinality of P by $\#P$. A participating firm invests A to implement the invention, and payoffs are realized. Let π_j denote the probability that firm $j \in P$ will receive a high-quality invention, given the TTO's selection rule σ. That is,

$$\pi_j (s_j) = \sum_{m=1}^{n} s_j (m) \lambda (m),$$

where

$$\lambda (m) = \binom{n}{m} p^m (1 - p)^{n-m}$$

Let $\tilde{\pi}_j$ be firm j's belief that it will obtain a high-quality invention, and $\tilde{P}$ be the subset of firms that the TTO believes will participate in technology transfer, $\tilde{P} \subseteq K$. The expected payoff of a firm $j \in K$ from licensing an invention is

$$\left(1 - \rho_j\right) \beta_j \left[\tilde{\pi}_j V_H + (1 - \tilde{\pi}_j) V_L\right] - A, \tag{1}$$

and the expected payoff of the TTO from investing in expertise is

$$\sum_{j \in \tilde{P}} \rho_j \beta_j \left[\pi_j V_H + (1 - \pi_j) V_L\right] - C \tag{2}$$

We assume that firm j is willing to participate in technology transfer whenever its expected payoff from licensing, as given by (1), is nonnegative. Similarly, the TTO is willing to invest in expertise whenever its expected payoff, as given by (2), is nonnegative. A necessary condition for intermediation activity is thus

$$\sum_{j=1}^{k} \beta_j V_H - kA > C, \tag{A3}$$

[10] Note that the model covers the two most frequently used licensing methods for university inventions, royalty (fee per unit of output) and equity contracts (Jensen and Thursby, 2001; Jensen et al., 2001). For simplicity we neglect the possible output distortion induced by royalties through their effect on the marginal cost of production.

which states that the cost of expertise is smaller than the largest possible social gains from innovation. We assume that A3 holds.

3 Intermediation equilibria

The model of Section 2 characterizes a situation where no firm has an incentive to commercialize an invention due to uncertainty about its profitability. In this section, we show that the intermediary may find it profitable to mitigate this uncertainty problem and induce firms to invest in innovation. Our analysis focuses on perfect Bayesian equilibria and involves two steps. In the first step, we present the perfect Bayesian equilibria that are sustainable for a large number of inventions. The purpose is to give an idea on how intermediation works in our model. The second step characterizes the efficient equilibrium in which the social gains from innovation are maximized.

Proposition 1 *For n large enough there are two kinds of perfect Bayesian equilibria:*

1. *TTO invests in expertise, firms in P participate and firms in $K-P$ do not participate where $\emptyset \neq P \subset K$ is such that $\sum_{j \in P} \left(\beta_j V_H - A\right) \geq C$.*
2. *TTO does not invest in expertise.*

Proof. First we construct an equilibrium where TTO invests in expertise, firms in P participate and firms in $K - P$ do not participate where $\emptyset \neq P \subset K$ is such that $\sum_{j \in P} \left(\beta_j V_H - A\right) \geq C$. Suppose that the TTO's strategy σ is such that $s_j(m) = 1$ for $j \in P$ if $m \geq \#P$ and $s_j(m) = 0$ for $j \in K - P$ if $n - m \geq k - \#P$. (This description only partially describes the TTO's strategy but it is enough to construct the kind of equilibrium that we are looking for.)

Let $\beta_k V_H - A = \Delta$. By Assumption A2, $\Delta > 0$. Under the TTO's strategy, the probability that a firm j in P obtains a good invention, $\pi_j(s_j)$, is at least $\sum_{k \leq m \leq n} \lambda(m)$, which goes to 1 as n gets large. To see this, note that

$$\begin{aligned} \pi_j(s_j) &= \sum_{m=1}^{n} s_j(m) \lambda(m) \\ &= \sum_{1 \leq m < k} s_j(m) \lambda(m) + \sum_{k \leq m \leq n} s_j(m) \lambda(m). \end{aligned}$$

Under the TTO's strategy,

$$\sum_{m \geq k} s_j(m) \lambda(m) = \sum_{m \geq k} \lambda(m).$$

Thus,

$$\pi_j(s_j) \geq \sum_{k \leq m \leq n} \lambda(m) \to 1 \text{ as } n \to \infty.$$

Therefore when n is large enough,

$$\beta_k \pi_j(s_j) V_H + \beta_k (1 - \pi_j(s_j)) V_L - A > \frac{\Delta}{2} > 0.$$

Suppose the TTO chooses $0 < \rho_j < 1$ so that

$$\rho_j [\beta_k \pi_j(s_j) V_H + \beta_k (1 - \pi_j(s_j)) V_L] - A = 0.$$

In this case, given the TTO's equilibrium strategy, the firms in P participate.

Similarly, under the TTO's strategy, the probability that a firm j in $K - P$ obtains a bad invention, $1 - \pi_j(s_j)$, is at least $1 - \sum_{m=n-(k-\#P)+1}^{n} \lambda(m)$,which goes to 1 as n gets large. Therefore by assumption A1, when n is large enough,

$$\beta_k \pi_j(s_j) V_H + \beta_k (1 - \pi_j(s_j)) V_L - A < 0.$$

Therefore, firms in $K - P$ will not participate for any choice of ρ_j.

Finally, given that firms in P are participating, the surplus that the TTO extracts is $\sum_{j \in P} \left(\beta_j V_H - A\right) \geq C$, therefore the TTO enters.

Note that when the TTO believes that the set of firms participating in equilibrium, P, is such that $\sum_{j \in P} \left(\beta_j V_H - A\right) \geq C$, then the TTO always invests in equilibrium. Therefore, the only other kind of equilibrium will be one where the TTO believes that if it invests firms in P participate and firms in $K - P$ do not participate where $P \subset K$ is such that $\sum_{j \in P} \left(\beta_j V_H - A\right) < C$ (if P is the empty set, then the right hand side is taken to be 0). The TTO's strategy if it invests is to set $s_j(m) = 1$ for $j \in P$ if $m \geq \#P$ and $s_j(m) = 0$ for $j \in K - P$ if $n - m \geq k - \#P$. With n large enough, exactly as we argued above, the TTO can choose the contracts ρ_j so that it is a best response for the firms in P to enter and others not to enter. Therefore, for the TTO it is optimal not to invest in the first place.

It is easy to see that these are the only two kinds of equilibria that can arise in this game. ■

The equilibrium with intermediation is sustained by the following considerations. First, with royalty payments the TTO benefits when a firm adopts a high-quality invention. In contrast, if the TTO were paid on a fixed basis, it would be indifferent between offering profitable and unprofitable inventions to potential investors. Thus, even though the TTO has no means to credibly reveal the true nature of an invention, potential investors can infer from the usage of success-based payments such as royalties that selecting inventions of high value is a priority for the intermediary.[11] Second, as the number of inventions, n, goes to infinity, the probability that a potential investor will be matched with a profitable invention converges to 1 under any equilibrium selection rule of the TTO. Indeed, we show that when the TTO is running royalties and the number of inventions exceeds a certain threshold level, expected payments from participating firms can be large enough to make the expertise investment profitable in equilibrium. Innovation then occurs in a situation where no innovation would occur without an intermediary, which helps explain the role of TTOs as intermediaries in the organization of innovation investments.

As it turns out, the relationship between the number of inventions, n, and a firm's willingness to pay is not necessarily monotonic. The reason is that, for n not too large and not too low, the model may possess perfect Bayesian equilibria in which more efficient firms are matched with unprofitable inventions, while less efficient firms receive profitable ones. In these equilibria, royalties are not monotonic in the firm's efficiency level. The following simple example illustrates this phenomenon.

Example 1 *There are four firms,* $K = \{1, 2, 3, 4\}$. *Let* $\beta_1 = 5, \beta_2 = 4, \beta_3 = 3, \beta_4 = 2.5$, $V_H = 1$, $V_L = 0.1$, $p = 0.1$, $A = 1$, *and* $C = 4$. *Then Assumptions A1-A3 are satisfied. We now construct a perfect Bayesian equilibrium in which firm 3 obtains a low-quality invention and firm* 4 *obtains a high-quality invention if* $m = 3$. *Let* $n = 30$. *Suppose the TTO's selection strategy is as follows:* $s_1(m) = 1$ *if* $m \geq 1$ *and* $s_1(0) = 0$, $s_2(m) = 1$ *if* $m \geq 2$ *and* $s_2(m) = 0$ *otherwise,* $s_3(m) = 1$ *if* $m \geq 4$ *and* $s_3(m) = 0$ *otherwise,* $s_4(m) = 1$ *if* $m \geq 3$ *and* $s_4(m) = 0$ *otherwise. This yields* $\pi_1 \simeq 0.95761, \pi_2 \simeq 0.8163, \pi_3 \simeq 0.35256$, *and* $\pi_4 \simeq 0.58865$. *Suppose firms have compatible beliefs. The TTO offers each firm* $j \in K$

[11] The finding can account for the frequent usage of payment schemes such as royalty (fee per unit of output) and equity contracts in university-industry technology transfer (see Jensen and Thursby, 2001; Jensen et al., 2001). In fact, fixed fees in university-industry licensing contracts are mainly used to cover the TTO's fixed costs of patent applications. Our analysis abstracts from such costs in order to emphasize the effect of success-based payments on the viability of intermediation. The role of royalty contracts as a signalling device has previously been studied by Gallini and Wright (1990) in a setting where an inventor has superior information about the value of its invention.

an invention and charges a royalty rate $\rho_1 \simeq 0.79207, \rho_2 \simeq 0.70048, \rho_3 \simeq 0.15332, \rho_4 \simeq 0.36486$, *respectively, such that the expected payoff for each firm* $j \in K$ *from licensing is zero. Hence,* $P = K$ *if the TTO invests in expertise. The TTO's expected license revenue is* $R \simeq 6.9035 > C$*, therefore the TTO invests in expertise. Thus, if the number of high-quality inventions turns out to be* $m = 3$*, the TTO will license a high-quality invention to each firm* $j \in \{1, 2, 4\}$ *, and a low-quality invention to firm* 3*. It is easy to check that, given the firms' beliefs, the TTO cannot gain by licensing a high quality invention to firm 3 and a low-quality one to firm 4. One can also easily check that such a deviation becomes profitable if the number of inventions,* n*, gets large enough, e.g.,* $n = 60$*, since royalties would then be monotonic in the firms' efficiency level, given the TTO's selection strategy and the firms' beliefs. Finally, if* n *gets sufficiently low, e.g.,* $n = 10$*, the TTO's expected license revenue would be lower than the cost of expertise, for any selection strategy. Therefore the TTO would not invest in expertise.* ■

In fact, the proposition also shows that no intermediation is always a possible equilibrium outcome. This equilibrium arises when the intermediary expects the set of participating investors to be empty, and hence the expected return to intermediation to be too low to make the investment in expertise attractive in the first place. On the other hand, the equilibrium without innovation is rather fragile. As one can show, every sequential equilibrium involves investment in expertise by the TTO if the number of inventions n is large enough.

In the following, we will identify a particular equilibrium in which the social gains from innovation are maximized.

Definition 1 *The efficient equilibrium is a perfect Bayesian equilibrium in which* $s_j(t) = 1$ *for all* $j \leq t$*.*

That is, in the efficient equilibrium each high-quality invention is assigned to the most efficient firms as long as there are fewer high-quality inventions than firms. In the case where there are more high-quality inventions than firms, all firms receive a high-quality invention.

Proposition 1 allows us to characterize the participation decision of firms only when the TTO has access to a large invention pool. Apart from being intuitively plausible, the efficient equilibrium also allows us to characterize the participation decision of firms when the invention pool is not very large. To be specific, define α by

$$\beta_1 [\alpha V_H + (1 - \alpha) V_L] = A$$

Now let $\hat{n}$ be the smallest integer such that

$$\alpha \leq \sum_{m=1}^{\hat{n}} \binom{\hat{n}}{m} p^m (1-p)^{\hat{n}-m} .$$

Thus $\hat{n}$ is the minimum number of inventions that would make it profitable for the most efficient firm to participate when it for sure gets a high-quality invention if there is one. If the invention pool is smaller than this, it can not be profitable for any firm to participate.[12]

Proposition 2 *Suppose $n \geq \hat{n}$. The game has an efficient equilibrium with a unique $\hat{k} \leq k$ such that all firms $j \leq \hat{k}$ obtain an invention if the TTO invests in expertise. Moreover, the TTO invests in expertise if*

$$\sum_{j=1}^{\hat{k}} \beta_j \left[\hat{\pi}_j V_H + (1-\hat{\pi}_j) V_L\right] - \hat{k}A \geq C \tag{3}$$

where

$$\hat{\pi}_j = \sum_{m=j}^{n} \binom{n}{m} p^m (1-p)^{n-m} \tag{4}$$

is the probability that firm j receives a high-quality invention in the efficient equilibrium.

Proof. Suppose that the TTO is using an efficient strategy, and whenever there is a positive expected surplus, offering contracts that give zero expected profits to firms if they participate. Otherwise the TTO offers any contract, and all such contracts give a negative expected payoff to the relevant firm. By definition of $\hat{n}$ the most efficient firm has a positive expected surplus and under the preceding strategy it clearly participates if the TTO invests in expertise and uses an efficient strategy. Therefore the equilibrium set of participating firms is $P \neq \emptyset$.

Now suppose towards a contradiction that there are firms $k_1 < k_2 \leq k$ such that $k_1 \notin P$ but $k_2 \in P$. The expected surplus for k_1 is positive since the expected surplus for k_2 is non-negative under the strategy of TTO. Thus firm k_1 also finds it profitable to participate, contradiction. It is easy to see that the TTO can not benefit from deviating from the efficient strategy once it invests in expertise. This establishes the first claim.

The second claim follows immediately from the first one. ■

[12] In the alternative interpretation of our model, where each firm can adopt more than one invention and k is the total number of innovation opportunities in the economy, the efficient equilibrium involves licensing to one or more firms such that all innovation opportunities $j \leq \hat{k}$ are realized.

An attractive feature of the efficient equilibrium is that it maximizes not only the licensing revenue for the TTO,[13] but also the number of licenses. Note that in the efficient equilibrium a firm participates only when positive surplus is generated from its participation, given that all firms that are more efficient are participating. Therefore there is no other allocation that would achieve a greater number of licenses. In this sense, even when the TTO's main objective is maximizing the number of licenses, it could not do better than what it achieves in the efficient equilibrium. Thus committing to maximizing revenues and playing the efficient equilibrium achieves multiple objectives for the TTO.[14] Since licensing revenues are maximized, this income may be used for further research, and this is done in a way that the number of licences is maximized.

Proposition 3 states another feature of the efficient equilibrium. The following example illustrates Propositions 2 and 3.

Proposition 3 *In the efficient equilibrium, the number of participating firms $\hat{k}$ is a monotone increasing function in the number of inventions n.*

Proof. In an efficient equilibrium, we have

$$\pi_j(n) = \sum_{l=j}^{n} \binom{n}{l} p^l (1-p)^{n-l}$$

which is a monotone increasing function in n. To see this note that

$$\binom{n+1}{l} = \binom{n}{l} + \binom{n}{l-1}$$

for $l \leq n$. Using this equality we can see that,

$$\pi_j(n+1) - \pi_j(n) = \binom{n}{j-1} p^j (1-p)^{n-j+1} > 0.$$

The result follows immediately. ■

[13]In the efficient equilibrium, the TTO's choice of royalty is monotonic in a firm's efficiency level.

[14]The recent survey of major U.S. universities by Jensen et al. (2000) reveals that the most important objective to a TTO is the generation of licensing revenue. 71% of the respondents (either directors or license officers of the TTOs) said that it is extremely important, and only one respondent indicated that it is not important. The second most important objective is the number of inventions commercialized, followed closely by the number of licenses.

Example 2 *There are four firms,* $K = \{1, 2, 3, 4\}$, *with efficiency parameters* $\beta_1 = 5$, $\beta_2 = 4$, $\beta_3 = 3$, $\beta_4 = 2.5$ *respectively. Let* $p = 0.1$, $V_H = 1$, $V_L = 0.1$, $A = 1$, *and* $C = 4$. *Then Assumptions A1-A3 are satisfied, and* $\hat{n} = 2$. *Let* $n = 10$. *If the TTO is using the efficient selection strategy and firms have compatible beliefs, the TTO's expected license revenue is* $R \simeq 2.6348 < C$. *Hence, if* $n = 10$, *there is no equilibrium in which the TTO invests in expertise. If* $n = 15$, *the efficient equilibrium exists with* $\hat{k} = 2$. *It involves* $\rho_1 \simeq 0.75451$, $\rho_2 \simeq .50579$, *and* $R \simeq 4.0969 > C$. *If* $n = 25$, *the efficient equilibrium exists with* $\hat{k} = 3$. *It involves* $\rho_1 \simeq 0.78619$, $\rho_2 \simeq 0.66927$, $\rho_3 \simeq .35477$, *and* $R \simeq 6.2505 > C$. *If* $n = 40$, *the efficient equilibrium exists with* $\hat{k} = 4$. *It involves* $\rho_1 \simeq .7973$, $\rho_2 \simeq .73048$, $\rho_3 \simeq .58306$, $\rho_4 \simeq .33239$, *and* $R \simeq 8.5401 > C$. ■

The empirical evidence given in Siegel et al. (2000) appears to be consistent with efficient equilibrium. Using a database of 113 U.S. universities, Siegel et al. find that the number of licensed inventions as well as the TTO's license revenue increase monotonically in the number of disclosed inventions.

4 Competition between intermediaries

In this section, we extend the intermediation model to allow for competition between intermediaries. While a complete analysis of competing intermediaries is beyond the scope of the present paper, a simple extension of our model reveals that the competition may be affected by the differences in the size of each intermediary's invention pool as well as the possibility to specialize on different innovator group that each intermediary serves.

We describe briefly the formulation of a model of competition between two TTOs, $i = 1, 2$. Denote the size of the invention pool of TTO i by n_i. The set of potential licensees is denoted by $K = \{1, 2, ..., k\}$ as before. We assume that $k \leq n_i$. The sequence of decisions is like that of the model in Section 2. In stage 0, the TTOs simultaneously choose a selection rule, denoted by σ_i for TTO i. Formally, $\sigma_i = \{s_j\}_{j \in K}$ is a set of functions, where $s_j : \{1, ..., n_i\} \to \{0, 1\}$ for each $j \in K$. Here $s_j(m_i) = 1$ means that firm j receives a high-quality invention from TTO i, and $s_j(m_i) = 0$ means that firm j receives a low-quality invention from TTO i, when there are m_i high-quality inventions. We assume that $\sum_{j=1}^{k} s_j(m_i) \leq m_i$, and $k - \sum_{j=1}^{k} s_j(m_i) \leq n_i - m_i$. In stage 1, the TTOs simultaneously decide whether to invest in expertise or not. The investment is observable. If neither of them invests, the game is over and payoffs to all players are zero. If TTO i invests, it observes the number of high-quality inventions, denoted by m_i, that are available in its invention pool n_i, where $m_i \leq n_i$. In stage 2, each TTO i offers each firm $j \in K$ an invention according to its selection rule σ_i, and simultaneously charges a royalty rate ρ_j^i, for the licensing the invention, where $\rho_j^i \in (0, 1]$ is a fraction of the firm j's revenue from adopting the invention. In stage 3, each firm accepts at most one license offer (or rejects both offers). We make the standard assumption that a firm faced with the same expected quality/royalty offer chooses to contract with TTO i with probability 1/2 and with TTO $-i$ with probability 1/2.

We denote the cardinality of each set of participating licensee-firms P_i by $\#P_i$. A participating firm invests A to implement the new technology, and payoffs are realized. Let π_j^i denote the probability that firm j will receive a high-quality invention from TTO i, given s_j, and let $\tilde{\pi}_j^i$ be firm j's belief about this probability. The expected payoff of a firm $j \in P_i$ is

$$\left(1 - \rho_j^i\right) \beta_j \left[\tilde{\pi}_j^i V_H + \left(1 - \tilde{\pi}_j^i\right) V_L\right] - A. \tag{5}$$

Let $\tilde{P}_i \subset K$ denote the subset of firms that TTO i believes would license one of its inventions. The expected payoff of TTO i from investing in expertise is

$$\sum_{j \in \tilde{P}_i} \rho_j^i \beta_j \left[\pi_j^i V_H + \left(1 - \pi_j^i\right) V_L\right] - C \tag{6}$$

As in the case of a monopoly TTO, the game of competing TTOs has multiple perfect Bayesian equilibria. This is due to the multiplicity of consistent beliefs of the firms about the selection strategies of the TTOs. In the following, we restrict attention to the existence of two extreme types of equilibria: (i) equilibria in which the TTOs employ the same selection rule, which allows us to highlight the effect of differences in the size of the TTOs' invention pools, and (ii) equilibria in which the TTOs employ a different selection strategy, which allows us to highlight the possibility to reduce the degree of competition.

4.1 Homogenous selection rules

We first analyze the case in which each TTO offers licenses to all firms, employing the same selection rule as the other TTO. First note that in any perfect Bayesian equilibrium in which both TTO's choose the same selection rule only one TTO can be active. To see this assume without loss of generality that $n_1 \geq n_2$, i.e. TTO 1's invention pool is at least as large as TTO 2's. Now suppose that there exists a perfect Bayesian equilibrium in which both TTOs invest in expertise and follow the same selection rule. Consider the associated continuation game, in which each TTO i sets a royalty rate, ρ_j^i, for each firm

$j \in K$. Since $n_1 \geq n_2$ and TTO's use the same selection rule $\tilde{\pi}_j^1 \geq \tilde{\pi}_j^2$ for any firm j. Firm j will contract with TTO i if:

$$\left(1-\rho_j^i\right)\beta_j\left[\tilde{\pi}_j^i V_H + \left(1-\tilde{\pi}_j^i\right)V_L\right] - A \geq \left(1-\rho_j^{-i}\right)\beta_j\left[\tilde{\pi}_j^{-i} V_H + \left(1-\tilde{\pi}_j^{-i}\right)V_L\right] - A$$

and if

$$\left(1-\rho_j^i\right)\beta_j\left[\tilde{\pi}_j^i V_H + \left(1-\tilde{\pi}_j^i\right)V_L\right] - A \geq 0.$$

Now suppose that firm j contracts with TTO 2 (i.e., the two inequalities above are satisfied for $i = 2$) and that

$$\rho_j^2\beta_j\left[\tilde{\pi}_j^2 V_H + \left(1-\tilde{\pi}_j^2\right)V_L\right] > 0,$$

that is TTO 2 makes positive profit from this firm. Then TTO 1 can slightly undercut TTO 2 by offering a royalty rate that is slightly below ρ_j^2, and given that $\tilde{\pi}_j^1 \geq \tilde{\pi}_j^2$, firm j will contract with TTO 1. This way TTO 1 can increase its profit. So for any firm j that contracts with TTO 2 it must be that

$$\rho_j^2\beta_j\left[\tilde{\pi}_j^2 V_H + \left(1-\tilde{\pi}_j^2\right)V_L\right] = 0.$$

But, this leads to a contradiction since in this case TTO 2 will not invest in expertise in the first place. We can summarize this discussion in the following proposition:

Proposition 4 *There exists no perfect Bayesian equilibrium in which both TTOs invest in expertise and use homogenous selection rules.*

The argument above suggests that we may expect the TTO with the larger invention pool to have an advantage in the Bertrand like competition and therefore to be the only one investing in expertise. However, the next example demonstrates that this is not generally true. There may exist equilibria in which the smaller TTO invests in expertise and the larger TTO does not invest in expertise.

Example 3 *There are two firms,* $K = \{1, 2\}$, *with efficiency parameters* $\beta_1 = 5$, $\beta_2 = 4$, *respectively. Let* $p = 0.1$, $V_H = 1$, $V_L = 0.1$, $A = 1$, *and* $C = 4$. *Then Assumptions A1-A3 are satisfied. There two TTOs,* $i = 1, 2$, *with* $n_1 = 20$ *and* $n_2 = 15$, *respectively. Suppose the TTOs are using the efficient selection strategy and firms have compatible beliefs. We now demonstrate that expertise investment by TTO 2 and no expertise investment by TTO 1 is a possible equilibrium outcome of this game. Suppose first that only TTO 2 invests in expertise, which yields* $\tilde{\pi}_1^2 = 0.79411$ *and* $\tilde{\pi}_2^2 = 0.45096$. *The expected license revenue for*

TTO 2 is then $R^2 \simeq 4.0969 > C$*. Suppose next that TTO 1 invests in expertise as well, which yields* $\tilde{\pi}_1^1 = 0.87842$ *and* $\tilde{\pi}_2^1 = 0.60825$*. It is easy to show that the only equilibrium of the continuation game involves* $\rho_1^1 = 0.10988$*,* $\rho_2^1 = 0.35621$*, and* $\rho_1^2 = \rho_2^2 = 0$*. The expected license revenue for TTO 1 is then* $R^1 = 0.94569 < 4$*. Hence, if TTO 2 invests in expertise, TTO 1 will choose not to invest in expertise.* ■

On the other hand, if the TTOs use homogenous selection strategies and the difference in the TTOs' invention pools gets very large, then in equilibrium only the TTO with the larger pool will invest in expertise. To see this, fix the size of one TTO's invention pool, say n_2. Note that when the difference $n_2 - k$ is not too large, then the probability of receiving a high-quality invention from TTO 2 is low for some firms. Moreover, when both n_2 and k are large, the number of such firms is large. Now if we choose n_1 large enough, these firms will receive a high-quality invention from TTO 1 with probability close to 1. So TTO 1 can charge a royalty rate such that these firms will choose to obtain a license from TTO 1, and therefore generate enough revenue to make the expertise investment attractive, regardless of whether TTO 2 invests in expertise or not. However, by the previous proposition, both TTOs cannot be active in equilibrium. While the results for homogenous selection rules may appear quite stylized, they clearly highlight the potential competitive advantage of pooling resources in intermediation.[15] The results may also help explain why some universities form regional networks and share a common TTO, such as for example Access Technology Across Indiana (ATAIN), a statewide alliance by universities in Indiana, including Indiana State University, Indiana University, and Purdue University.

4.2 Specialized selection rules

We now demonstrate the existence of equilibria in which both TTOs are active and employ different selection strategies. Let S_1 and S_2 be two sets of firms, with $S_1 \cap S_2 = \emptyset$, and $S_1 \cup S_2 = K$. That is, firms are partitioned into two disjoint sets and each firm is a member of one or the other group. For example, S_1 includes all odd-numbered firms and S_2 all even-numbered firms. We denote the cardinality of S_1 and S_2 by $\#S_1$ and $\#S_2$, respectively. For each $S \subseteq K$, define S^m to be the set of the m most efficient firms in S. (If $m > \#S$, then $S^m = S$.) We will use the following definition:

[15] Note that a difference in terms of reputation for high quality faculty apparently has similar effects.

Definition 2 *A specialization equilibrium is a perfect Bayesian equilibrium in which (i)* $s_j(m_i) = 1$ *for each* $j \in S_i^{m_i}$*, and (ii) and* $s_j(m_i) = 1$ *for each* $j \in S_{-i}^{m_i - \#S_i}$ *if* $m_i > \#S_i$.

That is, in a specialization equilibrium each TTO i assigns as many high-quality inventions as possible to the most efficient firms in S_i. If $m_i > \#S_i$, i.e. there are more high-quality inventions than firms in that group, the TTO assigns the remaining high-quality inventions to the most efficient firms in S_{-i}. Let S_1 be the priority group of TTO 1, and S_2 that of TTO 2.

To demonstrate existence of a specialization equilibrium, we make the following restrictions on the size of each TTO's invention pool. First, assume that $n_i \geq \hat{n}_{S_i}$, where $\hat{n}_{S_i}$ be the minimum number of inventions that would ensure participation of the most efficient firm in S_i in the efficient equilibrium of the monopoly intermediation game. By Proposition 3, such $\hat{n}_{S_i}$ exists. Obviously, if TTO i's invention pool is smaller, it can not be profitable for any firm $j \in S_i$ to obtain an invention from TTO i if i uses a selection rule that is consistent with specialization equilibrium. Second, assume that $n_i < \bar{n}_{S_i}$, where $\bar{n}_{S_i}$ is the minimum number of inventions that would ensure participation of the most efficient firm in S_{-i} in the efficient equilibrium of the monopoly intermediation game. Again, such $\bar{n}_{S_i}$ exists by Proposition 3.[16]

Proposition 5 *If* $\hat{n}_{S_i} \leq n_i < \bar{n}_{S_i}$ *for* $i = 1, 2$*, and* C *is not too high, the game has a specialization equilibrium.*

Proof. Suppose first that each TTO has invested in expertise. As a preliminary step, we verify that a specialization equilibrium, if it exists, must involves a set of licensing contracts that satisfy

$$\left(1 - \rho_j^i\right) \beta_j \left[\tilde{\pi}_j^i V_H + \left(1 - \tilde{\pi}_j^i\right) V_L\right] - A = 0$$

for any participating firm $j \in S_i$, $i = 1, 2$. Suppose firm beliefs are consistent with selection rules in a specialization equilibrium. Since $n_i < \bar{n}_{S_i}$, each firm $j \in S_{-i}$ who is not in the priority group of TTO i believes that the probability that it obtains a high-quality invention from TTO i is too low to make licensing from i profitable for any royalty rate ρ_j^i. Hence, faced with a contract offer from each TTO, each firm $j \in S_i$ always prefers a

[16] Clearly, if n_i gets too large, specialization in selection rules eventually becomes irrelevant, since all firms expect to be confronted with a high-quality invention from each TTO with very high probability. The integer $\bar{n}_{S_i}$ is used as an upper bound to simplify matters.

license from TTO i over a license from TTO $-i$. This implies that, given the other TTO's selection rule and compatible firm believes, setting a different royalty rate is no profitable deviation for a TTO.

We next check whether any TTO can gain by deviating from its choice of selection rule. Let j' be the least efficient firm $j \in S_i$ that obtains a high-quality invention from TTO i in the candidate equilibrium. Clearly, the best possible deviation for TTO i would consist of a reallocation of a high-quality invention from j' to a firm $j'' \in S_{-i}$, where $j'' < j'$, i.e., to a firm of the rival's priority group that is more efficient that firm j'. However, since $n_i < \bar{n}_{S_i}$, there exists no royalty rate that would induce firm j'' to license from TTO i, given the firm believes about the TTO's choice of selection rules. To see this, note that the described deviation would not change firm j'''s belief and hence its participation decision, because firms are unable to observe changes in selection rules. Thus, firm j'' expects to obtain a low-quality invention from TTO i with such a high probability that licensing from i is never profitable for that firm. Clearly, the same argument holds for any firm $j \in S_{-i}$. Hence, the TTO cannot gain by deviating from the candidate equilibrium strategy.

Finally, note that the licensing revenue obtainable from each firm $j \in S_i$ and hence the total revenue for each TTO i is positive. Investment in expertise is therefore profitable for each TTO if C is not too large. ■

Specialization is often observed in markets with intermediaries. Sometimes specialization involves investment in different kinds of expertise. For example, one TTO may specialize in biotechnology, whereas another one may specialize in communication technology. On the other hand, as the proposition shows, allowing TTOs to invest in specialized expertise is not necessary for the occurrence of specialization in our model. Specialization may simply arise from the possibility to partition the set of potential licensees into different subsets, even though the TTOs have no means to commit themselves to license only to firms of a certain subset. If each TTO uses a selection strategy that assigns as many high-quality inventions as possible to firms who belong to a certain priority group and if firms have compatible beliefs, each TTO effectively increases its demand from the firms in its priority group. As the proposition shows, this may allow each TTO to generate sufficient revenue to recoup the cost of expertise despite the existence of an active rival.

Note that specialization on different priority groups may cause an *ex post* waste of high-quality inventions. For example, in the case of $m_i > \#S_i$ and $m_{-i} < \#S_{-i}$, i.e., when the number of high-quality inventions in TTO i's invention pool exceeds the number of target firms, and vice versa for the other TTO, then TTO i may not find any licensees for the remaining $(m_i - \#S_i)$ high-quality inventions due to “pessimistic” beliefs of non-target firms against TTO i. Moreover, note that specialization equilibria involve expertise investments by two TTOs where investment by one TTO would have been sufficient to solve the uncertainty problem, provided the TTO had access to both invention pools. This suggests that combining TTO services may be a way to enhance efficiency of innovation investments.

5 Intermediation with inventor involvement

The above analysis abstracts from the inventors' role in the innovation process by treating the probability that an invention is of high quality as exogenous. In this section we endogenize this probability by assuming that it depends on the inventor's development effort and giving each inventor the choice of whether to expend such effort or not. We thus essentially combine our basic intermediation model with that of Jensen and Thursby (2001).

Let p_i be the probability that an invention i is of high quality. Following Jensen and Thursby, we assume that the probability of success depends on the inventor's development effort, which is not contractible. We make the simplifying assumption that $p_i = p$ if inventor i invests $E > 0$, and $p_i = 0$ otherwise, where $p \in (0, 1]$. Accordingly, we replace the assumption on the cost of expertise by assuming that

$$\sum_{j=1}^{k} \beta_j V_H - k(A + E) > C. \tag{A3'}$$

The sequence of decisions in the extended framework is as follows. The decisions at date 0 and date 1 remain as before. Let ρ_{ij} and ρ_{ij}^i denote the royalty rates for the TTO and the inventor i, respectively, from licensing invention i to firm j. In stage 2, the TTO offers each potential investors one invention, according to its selection rule σ, and simultaneously sets royalty rates ρ_{ij} and ρ_{ij}^i, where $0 < \rho_{ij} + \rho_{ij}^i \leq 1$. In stage 3, firms simultaneously choose to accept or reject the TTO's offer. If a firm accepts, a development stage follows in which the inventor of the offered invention can choose to increase the probability of success by expending efforts in the development of this invention. Since efforts are non-contractible, there is a moral hazard problem with respect to the inventor's effort, exactly as in the model of Jensen and Thursby. Finally, the outcome of the inventor's development effort is observed and the licensee-firm decides whether to invest A for the implementation of the new technology.

Denote the set of participating inventors by $Q \subseteq \{1, ..., k\}$. The expected payoff of a firm $j \in P$ is

$$\left(1 - \rho_{ij}^{i} - \rho_{ij}\right) \beta_j \left[\tilde{\pi}_j V_H + (1 - \tilde{\pi}_j) V_L\right] - A,$$

the expected payoff of inventor $i \in Q$ from engaging in development activity is

$$\rho_{ij}^{i} \beta_j \left[\tilde{\pi}_j V_H + (1 - \tilde{\pi}_j) V_L\right] - E,$$

and the expected payoff of the TTO from investing in expertise is

$$\sum_{j \in \tilde{P}} \rho_{ij} \beta_j \left[\pi_j V_H + (1 - \pi_j) V_L\right] - C.$$

Inventors, firms, and the TTO will participate whenever they obtain a non-negative payoff.[17] It is not difficult to check that any perfect Bayesian equilibrium with expertise investment involves royalty rates such that inventors and firms will participate and are left with zero surplus. That is, an inventor will be motivated to engage in the development of the new technology by tying his payoff to that of the licensee-firm, similarly as in Jensen and Thursby (2001). Apart from this, the analysis of the extended game is qualitatively the same as that in Section 3. Moreover, note that in principle any incentive contract could be directly signed between the inventor and the licensee-firm, once the match is made. This suggest that the intermediary's selection and matching activity, as emphasized in our paper, may be a crucial element of effective technology transfer.[18]

6 Concluding remarks

Summary Uncertainty about the profitability of investing in new technology can hinder innovation investments. In fact, investments can fail to take place, even when the investor would realize positive gains from innovation. This uncertainty creates a potential basis for intermediation to be profitable in equilibrium. We have demonstrated that an intermediary may provide an opportunity for potential investors to economize on a critical component of

[17] In Jensen and Thursby (2001) the TTO maximizes a weighted average of the expected payoffs accruing to the university administration and to the inventor. Since both parties are assumed to benefit from a higher license revenue, one can verify that their main results continue to hold if one assumes that the TTO acts only on behalf of the university, as in our model, and ensures inventor participation via an optimal incentive contract.

[18] The disclosure of new inventions to the technology transfer office has recently been identified as another crucial element in the transfer process, see Jensen et al. (2003).

innovation decisions: the expertise to evaluate the value of new inventions and match the profitable ones with potential investors. The acquisition of expertise by an intermediary exposes potential investors to asymmetric information. However, an increase in the number of commercializable inventions, coupled with the usage of success-based compensation schemes, such as royalties, can enhance the likelihood for an investor to be matched with a profitable invention. Thus, intermediation in innovation can become viable in equilibrium, considering all costs.

We have extended the basic intermediation model to multiple intermediaries. In particular, we have studied the effects of differences in the invention pool sizes and of specialization in selection rules. Furthermore, we have endogenized the inventor effort in the commercialization of new inventions, thus essentially combining our basic model with that of Jensen and Thursby (2001). We find that the qualitative results of our basic model generally carry over to the combined version.

Our study also identifies several limitations to the potential efficiency of intermediation activity. First, the intermediary's matching activity need not be fully aligned with society's interest. That is, there are equilibria in which less efficient firms receive profitable inventions, while more efficient firms obtain unprofitable ones. Second, the multiplicity of equilibria due to the large strategy space of the intermediary introduce a high potential of coordination failure. Moreover, no innovation investments is always an equilibrium outcome of the model. Third, we find that competition between intermediaries may be an additional source of inefficiency. In particular, the allocation of profitable inventions in the case of specialized intermediaries may not be ex post efficient.

Empirical evidence Our main findings are supported by empirical evidence. In their comprehensive study of the U.S. market for technology in the early twentieth century, Lamoreaux and Sokoloff (2002) find that trade between inventors and investors was considerably facilitated by the emergence of intermediaries, such as patent agents and lawyers.

Hsu and Bernstein (1997) observe in their case studies of university-industry technology transfer that a critical mass of research activity is often required to make intermediation viable. Using an econometric model, Siegel et al. (2000) estimate the impact of the number of disclosed inventions on the license revenue of TTOs. They find strong evidence of increasing returns to scale, which is consistent with our model. In their extensive field research on organizational practices of university TTOs, Siegel et al. discover that firms often view the skills and expertise of TTO staff as critical to the effectiveness of university-industry technology transfer. Nonetheless, they also find some TTOs appear to have little incentives to invest in expertise. Our results may provide a possible explanation for this observation. That is, universities may not have a pool of commercializable technologies large enough to make such an investment attractive. Of course, there are also cases where firms receive crucial information from other sources, making intermediary intervention less relevant. Audretsch and Stephan (1996) and Zucker et al. (1998), for example, find evidence that the personal characteristics of the inventors, such as the status of being a "star" scientists as measured in terms of research productivity or the receipt of a Nobel prize, can play an important role in attracting firms of the biotechnology industry. On the other hand, such cases appear to be a "right-tail of the distribution" phenomenon, which primarily happens at the very best universities with top scientists in each field. The model developed in this paper thus seems best applicable to "representative" universities and scientists.

Policy relevance Our framework may be useful to study the effects of a controversial U.S. regulatory reform related to government-sponsored research: the Bayh-Dole Patent and Trademark Amendments Act of 1980. The Bayh-Dole Act gave universities the right to retain title to and license inventions resulting from federally funded research, and permitted exclusive licensing between universities and industrial firms for these inventions.[19]

Since the passage of Bayh-Dole, the number of TTOs at U.S. universities and the number of academic licenses increased significantly.[20] We have seen that TTOs may play an important role in forming a market for university inventions if they are able to obtain sufficient royalty revenue to recoup the investment in expertise. Clearly, the possibility to generate license revenue depends on whether or not universities hold the property rights on their faculty inventions and are permitted to license on an exclusive basis.[21] This implies that effective intermediation became a viable option for universities only after the regulatory changes.

[19] The Bayh-Dole Act has recently been copied the in Germany and Japan, see, e.g., *Süddeutsche Zeitung*, "Hochschulen sollen Erfindungen vermarkten", October 27, 2000; *The Economist*, "The land of disappointments", March 04, 2000.

[20] According to a licensing survey by the Association of University Technology Managers (AUTM), AUTM membership increased from 100 TTOs in 1980 to more than 2100 in 1999, and the number of academic licenses increased by 133% over the period from 1991 to 1999. See the AUTM Web Page, <http://www.autm.net>.

[21] Without exclusive rights, firm incentives to invest in innovation tend to be considerably reduced due to the possibility of free rider effects (cf. Heller and Eisenberg, 1998; Buchanan and Yoon, 2000).

Future research The analysis and results of the paper seem to carry over to the context of underwriters and technology-based business incubators who intermediate between new start-up firms and potential investors, trying to convince a *particular* investor that a *particular* start-up firm is profitable. Venture capitalists differ from TTOs, underwriters, and incubators in that they raise money *in advance,* promising potential investors to reinvest the money in profitable projects on their behalf. Thus, addressing this form of intermediation would require a modification of our model by considering selection rules that do not depend on the identity of a particular investor and particular invention or project. Nonetheless, we expect the main conclusions of the paper to hold in such a context.

It seems important to bring our basic model of intermediation in innovation closer to reality by putting it in a broader perspective. For example, it would be interesting to know how incomplete information about the efficiency level of potential investors would affect intermediation. In addition, the possibility of product market competition between potential investors could usefully be integrated in the analysis. Finally, it seems worth exploring a wider range of strategic interaction between competing intermediaries such as the competition for talented inventors.

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